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9 **WATER QUALITY SCIENCE IN THE SACRAMENTO – SAN**
10 **JOAQUIN DELTA**

11 **Part I: Chemical Contaminants and Nutrients**
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18 A Review by the

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20 **Delta Independent Science Board**
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23 **Draft for Delta ISB Review**
24 **March 6, 2018**

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I. Overview

This review focuses on contaminants and nutrients in the Sacramento-San Joaquin Delta (the Delta), and on how findings about them have been sometimes used and sometimes neglected in decisions related to ecosystem health in the Delta. The review considers water quality measurements made both in support of basic research and as part of routine monitoring studies in the Delta. However, the topic of monitoring per se is not comprehensively covered in this review because the Delta ISB is in the initial stages of reviewing the extensive monitoring enterprise in the Delta. This review of water quality is based on a questionnaire of government agencies and science programs, interviews with water-quality specialists and users of water-quality data, relevant scientific publications, presentations observed in workshops and conferences, and public comments received on draft versions of the review. While we sought input from a broad range of stakeholders, we do not assume that we received a complete range of perceptions about this important issue. Additionally, water quality research and monitoring efforts are constantly evolving in the Delta, and several new programs and improvements were made as this review was being researched and prepared. This review should be considered to be part of an ongoing process by the Delta ISB, which will involve various approaches to this important issue in the Delta.

The main findings of this review, elaborated below, include:

1. It is not clear to us, or to many of the agency personnel and stakeholders that we discussed this issue with, how water quality data are being used in management decisions, and whether the data being collected are sufficient to support optimal management decisions and policies. We recommend continued and expanded use of water quality data in support of management decisions and policies.
2. Adaptive management, as outlined by the Delta Plan and the Delta ISB in previous documents, is rarely built into water quality programs. We recommend that more aspects of Delta water quality be managed adaptively.
3. Water quality too rarely enters into discussions about water supply and reliability. Water conveyance and storage can influence Delta water quality by affecting where, when, and how much freshwater is diverted.
4. Although several entities in the Delta fund research and monitoring activities that protect water quality in the Delta, these resources often support specific compliance needs. In any event, responsibility for maintaining in-Delta water quality should be broadly assigned, and more resources are needed to support coordinated and integrated water quality monitoring efforts.

GENERAL FINDINGS AND RECOMMENDATIONS:

1. Finding: There is little that is simple, and much that can be misconstrued, in the description and interpretation of water quality in the Delta. Because Delta water quality has different meanings, requirements and legal obligations among different users, discussions of water quality often do not start from a shared understanding. Moreover, water quality is also

influenced by materials from the atmosphere and the surrounding landscape, as well as by physical, chemical, and biological processes in the waters themselves.

Recommendation: A more comprehensive view of the multiple elements that comprise water quality in the Delta is needed among stakeholders. Improved development and use of both numerical and conceptual models of water quality in the Delta could help move towards this goal.

2. Finding: Although the Delta is one of the most studied estuarine systems in the world, there is still much uncertainty about nutrients and certain contaminants, especially those of emerging concern.

Recommendation: Additional research is needed to support better management of chemical contaminants and nutrients. Chemicals of emerging concern (CECs) and harmful algal blooms (HABs) will require increased vigilance and coordination of multiple agencies to combine their research efforts and expertise to protect both ecosystem health and drinking water safety.

3. Finding: Little attention has been paid to interactions among chemical contaminants, or to interactions between contaminants and other stressors.

Recommendation: Interactions between chemical contaminants and other stressors require more attention. This is of particular concern for the wide range of pesticides discharged into the Delta, the legacy loadings of mercury, and the natural inputs of selenium. Improved understanding of the interactive effects of multiple chemicals on the ecosystem is also needed.

4. Finding: There is sufficient science to show that some chemical contaminants, including certain pesticides, mercury, and selenium, are having deleterious effects on the health of organisms in the Delta. These effects likely are modified by chemical interactions as well as non-chemical stressors. In addition, agricultural pesticides and nitrates in groundwater may contribute to unsafe drinking water for some Delta residents.

Recommendation: There is a need to further assess the effects of chemical contaminants on the Delta ecosystem through holistic studies that combine toxicity testing and chemical analyses with fish and food-web monitoring. Ecological risk assessment should be incorporated into future studies. The quality of groundwater used for drinking water also requires greater attention, especially for individual wells that are not tested routinely.

5. Finding: Studies that emphasize broad questions about interactions among nutrients, food webs, and ecosystem processes will more effectively serve management needs, compared to narrower research on nutrient forms and their ratios.

Recommendation: Increased emphasis is needed on the effects of nutrients on the growth of aquatic weeds and the food web of the Delta. The large-scale application of herbicides to control aquatic weeds returns nutrients from decaying plants to the water, likely affecting primary productivity; such unintended impacts require more consideration.

6. Finding: There is no comprehensive contaminants monitoring and assessment program. The nascent Delta Regional Monitoring Program (Delta RMP) is a positive step, but its temporal and

spatial coverage is not sufficient to satisfy the need for information. Moreover, how contaminants affect ecosystem processes needs more attention from monitoring programs.

Recommendation: The Delta RMP needs more resources in order to expand the contaminants it monitors, along with expanding the temporal and spatial coverage of its measurements.

7. Finding: There is a perception that collaboration among agencies conducting monitoring is not systemic nor well organized in the Delta.

Recommendation: We have found this to be the case and assert that improved collaboration between agencies could lead to better linkages between water quality monitoring that is done for regulatory compliance, with that being done for special studies and in research programs. Likewise, there is a need for coordination of locations of water quality and biological monitoring sites.

8. Finding: Water-quality monitoring is often not done at frequencies commensurate with the variability of the contaminants. This is especially true at locations where flow is measured systematically. These measurements are needed to provide information about loadings and improve understanding of the role of key events in the delivery of contaminants to the Delta.

Recommendation: An understanding of spatial and temporal variability in contaminant delivery and the role of key events (e.g., first flush, floods) will contribute to better understanding and management of contaminants.

9. Finding: The California Water Quality Monitoring Council (CWQMC) can play a critically important role in making monitoring data available.

Recommendation: The CWQMC needs additional resources and authority to be more effective. There are multiple agencies that can assist in the effort to make monitoring data available.

10. Finding: Data management efforts do not match the complexity of water quality monitoring, assessment and management issues and needs in the Delta.

Recommendation: Data management efforts must be expanded, especially in the area of quality assurance and quality control. While there have been positive developments in data sharing, more is needed. Increased development and use of data visualization tools and support for data sharing resources could improve this important component of water quality management in the Delta.

II. Introduction: Overview of the ISB Review Process

A. Motivation and scope

The mandate of the Delta Independent Science Board (Delta ISB) includes reviews of science activities in support of adaptive management in the Delta. This review considers the scientific basis for assessing water quality in the Delta, and on how water quality information is being used in management decisions in the Delta, especially in support of adaptive management. The review focused on:

- Water quality data and information needs by the entities responsible for the management of Delta water quality.
- Assessing the water quality parameters that are currently being monitored, and what additional parameters may be necessary.
- Assessing the temporal and spatial resolution of water quality data collection needed to understand timing, magnitude, and trends of changes in water quality.
- Evaluating the current state and utility of water quality monitoring.
- Reviewing connections between habitat quality and water quality for species of interest.
- Examining how water quality data are being used in management decisions, including the technical basis of the data being generated, the utility of the different types of data, and whether the data are sufficient to support management decisions and policies.

Motivation

A healthy Delta ecosystem requires water of good quality. However, the definition of what is “good” water quality may vary at different locations in the Delta and be dependent on how water is being used (e.g., for drinking water, agriculture, and ecosystem needs). Likewise, regulations and management decisions differ when different water quality issues are considered. There is a perception, especially among Delta residents, that water quality is impaired in the Delta. Several specific water quality parameters are 303(d)-listed in the Delta and improvements are needed to address these problems. Ongoing attention to water quality concerns should continue, especially efforts directed at improving ecosystem health. Proposed changes in water conveyance and changes in hydrology, coupled with climate change, are likely to affect water quality (e.g., Sinha et al. 2017), providing further impetus and relevance for continued review of this topic.

Water quality is a complex subject and is closely linked to the coequal goals of providing a more reliable water supply for California and protecting and restoring the Delta ecosystem. Many agencies and groups monitor water quality, water flows, and ecological conditions in the Delta. However, even though science is increasingly telling us that ‘sublethal’ exposures to contaminants can profoundly affect fitness, and consequently survival and reproduction of many species (e.g., Fong et al. 2016; Baldwin et al 2009), there is no comprehensive program that monitors and assesses contaminants in the Delta. In addition, much of the monitoring and assessment of contaminants is neither comprehensive nor coordinated.

Scope

We focused on three areas: chemical contaminants (including mercury, methylmercury, selenium, and pesticides, as well as other chemical contaminants such as pharmaceuticals, personal care products, and CECs), nutrients, and drinking water constituents of concern. Concurrent with our review, the Delta Science Program convened an expert panel to specifically review the Delta RMP’s proposed monitoring design (Raimondi et al. 2016; Noon et al. 2017). This process was tracked as part of our broader review.

Water quality is defined in a variety of ways depending on the stakeholder group (e.g., for drinking water, agricultural use, and ecosystem health). The Clean Water Act (CWA) established the basic structure for regulating pollutant discharges into the waters of the United States and gave the Environmental Protection Agency (EPA) the authority to implement pollution control programs such as setting wastewater standards for industry (<https://www.epa.gov/laws-regulations/summary-clean-water-act>). The Safe Drinking Water Act (SDWA) is the federal law that protects public drinking water supplies throughout the nation. Under the SDWA, EPA sets standards for drinking water quality and, with its partners, implements various technical and financial programs to ensure drinking water safety (<https://www.epa.gov/sdwa>). Our review focused primarily on the effects of chemical contaminants on ecosystem health in the Delta, but incorporated human health and well-being by also considering drinking water.

We recognize that to understand water quality and ecological processes it is important to look at many components concurrently, including: disinfection by-products (DBPs), dissolved organic carbon (DOC), pH, total suspended sediment/turbidity and light penetration, and biological components such as chlorophyll, blue-green algae and cyanotoxins, and phytoplankton taxonomy and size. We evaluate how this information is integrated into existing monitoring programs.

This review did not consider salinity, temperature, or dissolved oxygen. Although the importance of these attributes as a component of overall water quality is clear, several other recent reviews have addressed salinity issues, and the scientific basis for both dissolved oxygen and temperature is strong already, while other aspects of water quality have not received as much attention. These aspects will be addressed in a future review by the Delta ISB.

B. The review process

Our analysis of the state of water quality science in the Delta is based on information gathered from: (1) a literature review of recent publications on the topic of water quality, (2) responses to a questionnaire distributed to several agencies (Appendix A), (3) in-person interviews with individuals involved in different aspects of water quality (Appendix C), and (4) comments received on a draft released for public comment. During the review process, members of the Delta ISB also attended meetings of the Pelagic Organisms Decline (POD) Contaminants Work Team, the Delta RMP, the Delta Nutrients Forms and Ratios Public Workshop, a University of California-Davis symposium on multiple stressors in the San Francisco Estuary, the CWQMC, and a workshop on CECs. Members of the Delta ISB also attended relevant talks and sessions at the Bay-Delta Science Conference in 2016. Relevant papers from the recently published State of Bay-Delta Science were also consulted.

A questionnaire developed by the Delta ISB was distributed to agencies/programs engaged in water quality work in the Delta. Responses to this questionnaire provided many useful insights about the state of knowledge, ongoing activities by Delta agencies/programs, and concerns. The questionnaire generated responses from twenty-three entities, representing a range of state and federal agencies involved in water quality science in the Delta. The respondents

1 represented agencies that acquire water quality data as well as users of water quality data
2 acquired by other agencies. The respondents included entities that use water quality data for
3 regulatory and compliance purposes (e.g., biological opinions), as well as those that oversee
4 water quality monitoring programs (e.g., USGS, DWR), and others driven by research questions.
5 Respondents were not asked to represent the views of their respective entity. Responses to the
6 questionnaire were diverse, and we appreciate the willingness of many people to provide a
7 wide range of perspectives about the nature of ongoing water quality science in the Delta as
8 well as future needs. This feedback also revealed some of the challenges associated with
9 current efforts to monitor water quality in the Delta. The raw materials for this report include
10 the responses, comments, and insights provided by the individuals and groups we consulted.
11 Italicized comments below are taken verbatim from questionnaire responses or from
12 interviews. These are intended to be a reflection of the respondents understanding of water
13 quality issues and the Delta ISB neither endorses, accepts, or discounts these comments.
14 However, because they provide a snapshot of the opinions of personnel involved in water
15 quality assessments in the Delta, we believe these views are useful to highlight. A fuller listing
16 of written comments received, along with a graphical representation of the distribution of
17 responses to the questions, is presented in Appendix A, and a list of the respondent's entity is
18 presented in Appendix B.

20 C. Current and future threats to water quality

21 Factors that affect the Delta and its water quality have been identified in a series of reports and
22 publications (e.g., Lund et al. 2007; Mount et al. 2006; Healey et al. 2008; David et al. 2015) and
23 recent papers published in *San Francisco Estuary and Watershed Science* (SFEWS). These
24 reports and articles include discussions of, but are not limited to, population growth and
25 increased urbanization; wastewater inputs; agriculture and associated use of fertilizers,
26 herbicides, and pesticides; water sources and management practices; HABs; landscape
27 alteration; sea-level rise; and regional climate change. These studies are important to managing
28 water quality in the Delta because availability of high quality water affects the management of
29 endangered species, food webs, the fate of irrigation drainage, wastewater management,
30 treatment of drinking water, and numerous other activities in the Delta and throughout
31 California. Moreover, we included information from some presentations that we attended at
32 various scientific meetings and workshops.

34 California's complex water management system, as well as the supplies and demands on this
35 system, influence the quantity and quality of water in the Delta (Lund 2016). Moreover,
36 proposed plans to build diversion tunnels that use different points of diversion than presently
37 used (e.g., California WaterFix) and the construction of new storage and conveyance
38 infrastructure (e.g., surface reservoir projects) could result in changes in the amount of water
39 withdrawn and the quality of water in the Delta. These proposed changes in infrastructure and
40 water management could have adverse effects on the Delta ecosystem (e.g., Delta ISB 2015).

42 Likewise, there could be unexpected and unintended consequences from the above-mentioned
43 actions that will affect water quality in the Delta in the future. Changes to diversion points and
44 the potential for larger amounts of water to be withdrawn could affect Delta water quality and

1 alter water-residence times, which would further affect water quality. These issues should be
2 considered more carefully in discussions about, and planning for, these potential projects
3 (Schoellhamer et al. 2016).

4
5 In addition, the anticipated effects of climate change on hydrology and water reliability have
6 broad implications for every aspect of water and environmental management and are essential
7 to consider in development of any plan for water quality in the future. Projections indicate
8 trends that will result in reduced water storage from loss of snowpack, earlier runoff, larger
9 floods, and more extreme events (Cayan et al. 2008; Cloern et al. 2011). Climate change,
10 including sea level rise, is expected to lead to more frequent and extended periods of drought
11 as well as more frequent and intense floods and changes in salinity (Lund 2016 and references
12 therein). These events will influence water quality both by altering the delivery of contaminants
13 and pathogens as well as changing the residence time of water quality constituents. Storms and
14 floods have been shown to increase runoff of sediment, organic matter, nutrients and
15 contaminants from land to adjacent water bodies and increase eutrophication (Sinha et al.
16 2017). Periods of drought lead to less dilution of contaminated point sources in receiving
17 waters and alter water residence time, which may lead to reduced water quality in regions with
18 poor circulation. Drought periods also affect groundwater and water quality in wells used for
19 drinking water. The recent prolonged drought highlighted the interconnectedness of drought
20 with these issues and implications for water quality.

22 III. Current State of Science Regarding Water Quality in the Delta

23 A. Chemical contaminants and nutrients are among multiple stressors impacting the Delta
24 Numerous panels, boards, and agencies have clearly stated that multiple stressors are
25 impacting the Delta, and that a management focus on any one stressor, or limited group of
26 stressors, is not appropriate (Delta ISB 2011, NRC 2012, Mount et al. 2012). Instead, strategies
27 are needed to ameliorate each of those stressors that are considered to be significant.
28 Significant stressors in the Delta are acknowledged to include alterations in hydrologic flow,
29 water diversions, non-indigenous species, chemical contaminants, and nutrients. Here we
30 provide brief descriptions of chemical contaminants and nutrients, and in part B (below) we
31 describe them, and the status of Delta science concerning them, in more detail.

33 1. Chemical contaminants

34 For this review, we generally considered chemical contaminants to comprise those substances
35 that are substantially derived from human activities, and major sources of chemical
36 contaminants to the Delta include treated industrial and urban wastewater, agricultural and
37 urban runoff, and atmospheric deposition. Major classes of contaminants are: polycyclic
38 aromatic hydrocarbons (PAHs) that largely derive from fossil fuels or various combustion
39 processes; organohalogen compounds (OCs) such as polychlorinated biphenyls (PCBs) and
40 legacy pesticides such as DDTs; mercury and methylmercury; selenium; and current use
41 pesticides for both agriculture and domestic use. It should be noted that in the Delta, some

pesticides are also applied directly to surface waters for the control of non-indigenous aquatic plants.

There also is a growing list of chemical contaminants classified as ‘chemicals of emerging concern,’ or CECs. These are chemicals for which society is only recently becoming aware of their potential to cause environmental harm, whether because of previously unknown toxicity, increasing manufacture and releases, or both. CECs in the Delta include recently-registered pesticides, flame retardants, pharmaceuticals and personal care products (PPCPs), and microplastics (either specifically manufactured microplastics, or microplastics formed by the physical breakdown of larger pieces of plastics). The discussion of chemical contaminants is perpetually clouded by the plethora of substances that are included or not included by different authors, and the multiple routes by which these substances are transported into and through the environment.

2. Nutrients

For purposes of this report, nutrients refer to the dissolved inorganic forms of nitrogen (nitrate and ammonium), total dissolved and particulate nitrogen [TN], and phosphorus (orthophosphate and total phosphorus [TP]) that are major factors regulating the growth of algae and other aquatic plants. The largest loads of these nutrients to the Delta derive from the Sacramento and San Joaquin rivers, with agricultural and municipal discharge providing the main sources (Kratzer et al. 2011). Agricultural sources are composed of irrigation return flows that transport fertilizer and soil-derived nutrients and discharge from dairies and feedlots. Municipal discharge of treated wastewater from Publicly Owned Treatment Works (POTWs) is also a significant source of nutrients to the Delta. In combination with upstream and in-Delta sources, POTWs account for ~25% of the TN and 20% of the TP loads to the Delta (Dahm et al. 2016). Most of the ammonia delivered to the Delta derives from the Sacramento Regional Wastewater Treatment Plant (SRWTP), which contributes about 90% of the annual load of total ammonia to the Sacramento River at Freeport in the north Delta (Jassby 2008; Dahm et al. 2016). Nutrients (notably, nitrates) are also introduced to groundwater from agricultural drainage and may contribute to unsafe drinking water for some Delta residents using private wells. Nitrate accumulations in groundwater and soil in regions within the Central Valley arise from historic and ongoing discharges from legal and accepted agriculture, municipal, and industrial activities (Central Valley Water Boards, n.d.). The nitrate concentrations are impacting drinking water quality and, in some communities, water supply wells do not meet safe drinking water standards.

B. Status of Delta science on several major water quality issues

In the sections below, we *briefly* summarize the known threats for different water quality constituents to humans and wildlife, current science efforts addressing the threats, relevant comments from interviews and responses to a questionnaire, and the Delta ISB’s assessment of the adequacy of the science.

1. Drinking Water

Contaminated water is estimated to result in more than half a million deaths per year worldwide. Nationally, recent attention has been drawn to contaminants in the drinking water of Toledo, Ohio, and Flint, Michigan. In California, as in most of the United States, however, contaminant effects of concern in drinking water differ from contaminant effects on the ecosystem, although contaminants can affect the ability to meet standards, treatment requirements, aesthetic qualities of drinking water, water management programs, and drinking water provision costs (e.g., Fong et al. 2016). In California, public water systems are regulated and monitored by the Division of Drinking Water of the State Water Resources Control Board (SWRCB), commonly referred to as the Drinking Water Program (DWP). The DWP regulates ~7,500 public water systems (PWS) in California (SWRCB Annual Compliance Report, 2015). PWSs are divided into three principle classifications: community water systems (CWS); non-transient non-community water systems (NTNC); and transient, non-community water systems (TNC). These PWSs do not include private wells supplied by groundwater, which are common in some regions of the Delta and are sometimes impacted by high levels of bacteria, nitrates, and agricultural pesticides.

The Delta is an important source of drinking water for ~25 million people in the San Francisco Bay Area, Central Valley, and southern California. Priority drinking water quality issues described by Luoma et al. (2008) in the Delta water supply included salinity, bromides, and natural organic matter, and even today these remain important issues for Delta drinking water supplies. New drinking water regulations, adopted or proposed by the EPA and the SWRCB's Division of Drinking Water, drive additional monitoring and science needs. Contaminants receiving attention in the Delta include pathogens, cyanotoxins, pharmaceuticals, PCPs and CECs, and DBPs and their precursors. For example, organic carbon reacts with drinking water treatment disinfectants to form carcinogenic byproducts, which are regulated to be at low levels to protect public health (NRC 1980). Bromide, a component of salinity, also contributes to the formation of carcinogenic DBPs during the water treatment process. Levels of these constituents in Delta water may vary in response to hydrology, environmental conditions and water project operations (Kraus et al. 2008).

As one respondent noted, there is a need to,

“develop tools and briefings to make clear that water quality is important and that the attitude of many big diverters that wet water is preferable to clean water (because ...less clean water can be treated later) is harming the Delta. After all, the multi-barrier approach to drinking water quality requires that source water quality be protected. The excessive diversions in the Delta and upstream have meant that the water diverted and exported and later used for drinking water purposes and farm irrigation is no longer of desirable quality. Education is the first big step. After that the big diverters may be more comfortable and caring about water quality in the Delta.”

And, in terms of future needs,

1 *“For drinking water purposes, existing monitoring captures most of what is needed.*
2 *Additional monitoring and better availability of toxic algal bloom data would be helpful but*
3 *it is unclear at this time whether the recent programs will be sufficient to not only identify*
4 *locations of blooms but provide enough data to predict blooms in advance.”* However,
5 another respondent noted that multiple reviews focus *“on chemical constituents....”* but not
6 including microbes is a problem because *“they rarely get included anywhere/by anyone,*
7 *even though they are enormously important ecologically and for public health.”*
8

9 Currently, DBPs in the Delta water supply are effectively managed using existing treatment
10 standards and facilities. However, sea level rise and/or western-island levee failures could make
11 treatment of Delta water for urban use more difficult and expensive. Bromide from seawater,
12 combined with DOC is a particularly problematic precursor of DBPs. Likewise, drinking water
13 contamination in wells is an issue of ongoing and future concern.
14

15 2. Nutrients

16 The traditional view of nutrients in the Delta is that concentrations of nutrients are high and
17 nutrient limitation is uncommon. Factors other than nutrients, such as filter feeding by invasive
18 clams and light limitation are thought to regulate the rates of primary production (Jassby et al.
19 2002; Dahm et al. 2016). However, in recent years, nutrient concentrations, the form these
20 nutrients take, and ecosystem responses have become important topics for monitoring and
21 research in the Delta (Dahm et al. 2016). This interest in nutrients has arisen from changes in
22 water clarity, increasing frequency of HABs, the spread of aquatic water weeds and alterations
23 to the food web of the Delta.
24

25 The effects of nutrients on primary producers within the Delta depend on the light regime
26 (water clarity) and grazing pressure, which influence rates of primary production at different
27 times and locations within the Delta. The issue is critical for ecosystem management because of
28 the importance of phytoplankton carbon biomass in supplying much of the organic matter to
29 the estuarine pelagic food-web (Sobczak et al. 2005). Nutrient distributions also likely influence
30 HABs and invasive aquatic vegetation.
31

32 Overall, primary producer responses to nutrients have been relatively under-studied in the
33 Delta. Examples of gaps in knowledge include the effects of irradiance on nitrogen assimilation,
34 understanding nutrient uptake in wetlands, which is important because of plans for large-scale
35 restoration of wetlands, and measuring rates of phytoplankton uptake of phosphorus in the
36 Delta (Dahm et al. 2016). Phytoplankton-nutrient processes in the estuary are largely
37 unexplored due, at least in part, to the view that light-limited conditions buffer the Delta from
38 the common negative effects of high nutrient loads and concentrations (e.g., “blooms” and
39 ensuing eutrophication observed in systems such as Chesapeake Bay). In recent years, there has
40 been a surge in attention to inorganic nutrients as a control on phytoplankton primary
41 production within the San Francisco Estuary and Delta. Such work has responded to the debate
42 surrounding the “Ammonium Hypothesis.”
43

The “Ammonium Hypothesis” (also called, the “Ammonium Paradox”) links low production in the Delta to high concentrations of ammonium (Dugdale et al. 2007; Parker et al. 2012). The underlying assumptions to this hypothesis include that: (1) elevated ammonium concentrations inhibit nitrate uptake; (2) nitrogen uptake is higher when phytoplankton use nitrate vs. ammonium; and (3) phytoplankton primary production is lower when phytoplankton use ammonium rather than nitrate (Dahm et al. 2016). Each of these hypotheses has received scrutiny and efforts to understand the Ammonium Hypothesis resulted in a workshop hosted by the Nutrient Stakeholder & Technical Advisory Group (Nutrient STAG) and a resulting white paper (Ward and Paerl 2017).

The workshop findings, as summarized in the white paper (Ward and Paerl 2017), suggest that the Ammonium Hypothesis contributed to an “over-emphasis on only one part of a larger complex of drivers in the Delta that result in observed nutrient and phytoplankton patterns.” The white paper highlights that “a narrow focus on two different forms of nitrogen will not yield scientific findings that will result in effective, future management practices” and that a “broader understanding of critical Delta features that drive nutrient distribution, concentrations, forms and biological transformations is now needed to interpret results of previous experiments and forge a management path.” As a result, their panel recommended that future research should include “thoughtfully designed field studies in broadened, ecosystem-scale, prioritized theme areas as a better way to more thoroughly illuminate phytoplankton-nutrient interactions in the complex Delta landscape and, ultimately, make progress on Delta nutrient management strategies.”

Several of the questionnaire respondents noted the need for a better understanding of nutrients in the Delta including nutrient measurements over a larger range of spatial and temporal scales and greater consideration of nutrients in management decisions influencing threatened or endangered species. The white paper from the Nutrient STAG workshop and comments from respondents to the Delta ISB’s questionnaire support the need for more holistic approaches when considering nutrient effects on the Delta ecosystem. Questionnaire respondents also identified a need for more high frequency data, especially at locations where flow and water quality parameters are measured concurrently. The Delta Regional Monitoring Program and the Delta Stewardship Council are currently funding studies of high-frequency nitrogen data. This type of information will improve understanding of key processes and allow study of events such as floods, droughts and the upcoming conversion of the SRWTP. Planning and technical guidance for interpreting high-frequency nutrient data and integrating these data with other data sets is needed. As mentioned above, sensor technology is advancing, and improvements in sensor technology may make it feasible to establish a long-term, high-frequency base monitoring network to address questions of management concern and evaluate specific wetland restoration actions.

3. Pesticides

Pesticides are substances that are purposefully applied in order to control undesirable organisms. The term ‘pesticide’ most commonly encompasses herbicides, insecticides,

1 fungicides, and rodenticides, although there are also other types of pesticides. Over 13,000
2 pesticide formulations are registered for use in the state of California, which contain over 1,000
3 active ingredients, and more than 60% of those formulations are applied in the Central Valley
4 (California Department of Pesticide Regulation (CDPR; <http://www.cdpr.ca.gov/>), as reported
5 by Fong et al. 2016). Herbicides are the most commonly applied pesticides, generally making up
6 around 80% of the pesticides applied worldwide.

7
8 Numerous studies have determined the effects of some commonly used pesticides on fish and
9 invertebrates resident in the Delta, often showing deleterious effects across a wide range of
10 biological systems (reviewed in Fong et al. 2016). Depending on the pesticide, systems affected
11 include immune function, growth, reproduction, skeleto-muscular function, tissue structure,
12 development, and behavior. These effects can occur at pesticide concentrations similar to levels
13 measured in ambient waters of the Delta (Connon et al. 2009). While many of these effects are
14 commonly termed ‘sublethal effects,’ studies in other systems have shown that these types of
15 effects can scale up to have impacts on fish populations (Baldwin et al. 2009). Recent analyses
16 conducted by Fong et al. (2016) showed “significant correlations between pyrethroid use and
17 declining abundance of POD fish species” in the Delta. While correlation does not demonstrate
18 causation, the strength of the correlation is intriguing, and indicates that additional
19 investigation of this relationship is needed.

20
21 Pesticides occur in the Delta as mixtures, and in combination with other stressors such as
22 higher temperatures, lower dissolved oxygen, and pathogens. Mixtures of pesticides can often
23 have more than additive (e.g., synergistic) effects (Laetz et al. 2009, 2015). Consequently, the
24 frequent occurrence of multiple pesticides in Delta water samples (Orlando et al. 2013) is of
25 concern. Immunosuppressive effects of pesticides will negatively affect an organism’s ability to
26 resist pathogens, and it has been shown that increased temperatures can increase the toxicity
27 of pesticides to juvenile coho salmon (Laetz et al. 2014).

28
29 Thus, while there is sufficient science to show that pesticides have the potential to be exerting
30 deleterious effects on the health of individual organisms in the Delta and may also exert
31 downward pressure on populations of several fish species, additional research could provide a
32 better mechanistic understanding of these effects. For example, a major science gap exists with
33 respect to monitoring of pesticides in the waters and sediments in the Delta and determining to
34 what extent the pesticides present are affecting Delta species. Several responses to the
35 questionnaire called for greater effects-based assessment of chemical contaminants in the
36 Delta, especially for pesticides. For example, one response was “*We need to examine potential*
37 *water and sediment toxicity with a diverse suite of test species.*” Another was “*Toxicity testing*
38 *and the other biological tools available that assess the health of organisms or biological effects*
39 *of exposure are highly underused.*” Toxicity testing of ambient water and sediment samples is
40 one focus of the recently developed Delta RMP. However, the Delta RMP acknowledges that
41 their current level of effort, in terms of both spatial and temporal coverage, is not adequate to
42 meet the need. As one respondent said in response to our questionnaire “*there does not*
43 *appear to be sufficient information for regulatory agencies to prioritize aquatic ecosystem*
44 *health over anthropogenic interests.*” Developing such information on toxicity and other effects

1 is a formidable task. A recent study by Biales et al. (2015) attempted to provide such
2 information, using a wide array of endpoints and detailed chemical analyses of water, at four
3 sites in the Delta. While effects were seen, these authors also concluded that:

4
5 *“No clear linkages of specific analyte exposure to biological response were observed, nor*
6 *were linkages across biological levels of organization. This failure may have resulted from*
7 *limitations of the scope of molecular endpoints used, inconsistent timing of exposure, or*
8 *discordance of analytical chemistry through grab sampling and longer term, integrative*
9 *exposure. Together, results indicate a complicated view of the watershed.”*

10
11 In addition to better monitoring of pesticides and toxicity testing of ambient environmental
12 samples, there is likely a need to lower pesticide loadings in the Delta, by reducing applications
13 or further developing methods to minimize transport of pesticides to surface waters, or both.
14 The Delta is a highly productive agricultural area, and pesticides will continue to be used. One
15 recent report pointed to the effectiveness of vegetated agricultural drainage ditches in reducing
16 the transport of organophosphate and pyrethroid pesticides from fields in the Delta (Moore et
17 al. 2011).

18 19 4. Mercury and Selenium

20 Contaminants that biomagnify in the environment by increasing the concentration of a
21 substance in the tissues of organisms at successively higher levels in a food chain pose major
22 risks to aquatic species at higher trophic levels in the Bay–Delta, including fish, birds, and
23 mammals. Two contaminants that bioaccumulate, selenium and mercury, were identified by
24 Luoma et al. (2008, 2015) as pressing problems of water quality, both in the Delta and in other
25 parts of the San Francisco Bay estuary. As a result, we focus on these contaminants in this
26 section.

27 28 **Mercury**

29 Mercury is a neurotoxin that is poisonous to the nervous tissue of humans and other animals.
30 The deleterious effects of mercury exposure depend on the form of mercury (e.g.,
31 methylmercury (MeHg), elemental (metallic) mercury), the concentration, the length of
32 exposure, the overall health of the organism, and a variety of other factors (Bernhoft 2012). For
33 humans, exposure to methylmercury most commonly occurs when people eat fish and the flesh
34 of shellfish that have high levels of methylmercury in their tissues. For animals, mercury tends
35 to be an increasing problem as it concentrates (i.e., “bioaccumulates”) up the food chain,
36 especially in birds and fish (Bernhoft 2012).

37
38 Mercury, in the highly toxic form of methylmercury, can pose major risks to both aquatic and
39 terrestrial species at higher trophic levels, including fish, birds, and mammals. Methylmercury
40 exposure is a significant concern for special-status bird species in the Bay-Delta, including the
41 federally endangered Ridgway’s Rail (*Rallus obsoletus*), the California Least Tern (*Sternula*
42 *antillarum browni*), and Forster’s Tern (*Sterna forsteri*), which perhaps is the species at greatest
43 risk (Ackerman et al. 2014). Wood et al. (2010) note that the management plans for mercury in

1 both the Bay and the Delta should include a concentration target for prey fish to protect
2 piscivorous birds. Average concentrations of methylmercury in species of concern are also
3 commonly in the range known to affect biochemical processes, damage cells and tissue, and
4 reduce reproduction in fish, particularly in peripheral areas of the Delta (Sandheinrich and
5 Wiener 2011).

6
7 As one respondent noted,

8 *“Until about a decade ago, fish were thought to be insensitive to mercury toxicity;*
9 *however, research has found that they are as sensitive, if not more sensitive, as humans.*
10 *A recent study has implicated mercury toxicity to Delta fish species. In addition, many*
11 *studies have shown mercury toxicity to piscivorous birds in the Bay-Delta.”*
12

13 The management strategy for mercury adopted in 2003 (Weiner et al. 2003) launched a
14 comprehensive mercury research program in the Bay-Delta. However, continued funding for
15 this research program was lost with the dissolution of CALFED. The Delta methylmercury total
16 maximum daily load (TMDL) was adopted by the Regional Board on 22 April 2010. It was
17 approved by the SWRCB and the California Office of Administrative Law. Final approval by the
18 US EPA was received on 20 October 2011. The TMDL was adopted as a Basin Plan Amendment
19 and includes a control program to reduce methylmercury and inorganic mercury in the Delta.
20

21 Subsequent research appears to be mostly piecemeal and scattered. However, a recent
22 synthesis (Fleck 2016) presents a scientific foundation to build a unifying framework for
23 mercury research in the Bay-Delta and to generate knowledge that will help address the
24 primary threat from mercury in the region, which is human dietary exposure to mercury
25 through consumption of fish. The objective of this approach is to understand the link between
26 mercury sources and the regulatory end-point of fish tissue mercury concentrations.
27

28 Mercury concentrations vary spatially in the Delta. Notably, high concentrations of
29 methylmercury occur along the periphery of the Delta, while low concentrations (up to three-
30 times lower) are found in the central Delta. This is colloquially referred to as “The Delta
31 Doughnut.” Several reasons have been proposed to explain this spatial pattern: the periphery is
32 closer to legacy mining-related mercury sources; there is more mercury methylation in seasonal
33 wetlands at the periphery; there is more degradation and settling of tributary-sourced
34 methylmercury in open waters of the central Delta; and/or there is more tidal dispersion and
35 rapid flushing in the central Delta. Windham-Myers et al. (2016) incorporated various factors
36 related to these hypotheses into the CASCaDE hydrodynamic model to determine whether the
37 model can reflect concentrations in the central Delta compared to the peripheral Delta, which
38 could indicate which of the above processes may work together to influence the “doughnut”
39 phenomenon. An update on this effort was presented by Stewart et al. (2018).
40

41 Krabbenhoft et al. (2016) recently summarized the state of knowledge about mercury in the
42 Delta into three categories:
43

1 (1) *Issues that are generally well understood, which include:* spatial trends in total mercury and
2 methylmercury in water and sediment; methylmercury production in various ecosystems;
3 macroscopic mass balance (Hg & MeHg); toxicological effect on birds; a growing understanding
4 of how to reduce impacts of legacy mercury sources; and innovative land and water impact
5 reduction strategies including coagulation, wetland modification, and rice production.

6
7 (2) *Issues that are regarded as well understood but in actuality may require more information*
8 *and research, which include:* iron and sulfate reduction are key microbial processes driving
9 methylation; the relative importance of different mercury sources to MeHg production, such as
10 particulate-bound mercury being less important than dissolved mercury. Moreover, the
11 relationship between mine-related mercury and exposure risk is improving. In San Francisco
12 Bay, for example, legacy mining effects are more important than mercury from atmospheric
13 deposition. However, this relationship breaks down with distance from mines in the Delta
14 watershed. This has important implications for determining the effects of mine clean-up
15 activities downstream.

16
17 (3) *Issues that are best described as having gaps in knowledge:* these issues are summarized in
18 the next two paragraphs.

19
20 Much of the current information on mercury in the Bay-Delta is not directly comparable for
21 several reasons: there is no common database for mercury studies and monitoring; monitoring
22 and some of the methods used are not standardized; and data are not available at the level
23 needed to make robust inferences. Windham-Myers et al. (2016) used the information that is
24 available to develop a set of conceptual models that can be used to assess what types of
25 processes and associated risks are most important in a particular habitat or system. The
26 presumption is that these models can be used by managers to determine potential actions to
27 control mercury bioaccumulation. One suggested application is to integrate the conceptual
28 models with different control measures. However, Fleck (2016) showed that incorporation of
29 transport effects into conceptual models resulted in only slightly higher concentrations in the
30 central Delta and slightly lower concentrations in the periphery than what is found, indicating
31 that additional mechanisms are involved in mercury loss in the central Delta and mercury
32 generation in the periphery. Other modeling efforts have been used for developing TMDLs,
33 such as Cooke's use of data collected prior to 2008 to develop a mass balance box model for
34 mercury and MeHg (Cooke 2016). Additionally, more recent data should be used to update the
35 mass balances to adaptively manage the Central Valley Regional Water Quality Control Board's
36 Delta Mercury Control Program.

37
38 Gaps in knowledge about mercury in the Delta have been highlighted by Krabbenhoft et al.
39 (2016) and include: What are the temporal trends of mercury and methylmercury in biota and
40 water? What is the importance of hydrodynamics? Where and what are the main sources of
41 mercury and methylmercury? What is the importance of water chemistry and other factors?
42 How important are atmospheric sources of mercury? Are there links between environmental
43 and human health from mercury? We generally agree that these are important gaps in the
44 knowledge of mercury threats in the Delta. Krabbenhoft et al. (2016) also noted that there is no

common database for mercury studies and monitoring, and also recommended the collection of both filtered and non-filtered mercury samples to improve mass balance calculations and to better understand mercury sources.

Selenium

Selenium is an essential trace element and micronutrient that is of fundamental importance to animal health. However, in higher quantities selenium can cause a range of effects, including mortality, impaired reproduction, and embryo or larval deformities (Stewart et al. 2004, US EPA 2016). In aquatic environments, selenium exhibits a complex mode of toxicity. Selenium effects are further complicated by exposure pathways and bioaccumulation (Cutter and Cutter 2004). Dietary uptake of particulate selenium is the most important exposure pathway for aquatic organisms, especially predators, and some types of food webs bioaccumulate selenium more efficiently than others (Hamilton 2004, Stewart et al. 2004).

Selenium inputs to the Delta and San Francisco Bay come from natural (Nichols et al. 1986) and human (Luoma and Presser 2004) sources. Marine sedimentary rocks of the California Coast Ranges contribute selenium to soil, surface water, and groundwater in the western San Joaquin Valley. Because irrigation funnels selenium into subsurface drains and canals, it eventually flows into the Delta and San Francisco Bay. Although discharges from oil refineries have declined in recent years, they continue to be an additional source of selenium.

Scientific research on the effects of selenium on wildlife in the Delta and the Central Valley was greatly expanded when abnormalities were found in fish and various waterfowl and attributed to high selenium concentrations over three decades ago (Stewart et al. 2004). In the 1990s, selenium concentrations in biota in the North Bay were at levels considered to exceed thresholds leading to adverse effects in fish and wildlife (Luoma and Presser 2004). Because water with high concentrations of selenium flows through the Delta, recent studies in the Bay that examined effects of selenium on biota may have relevance to current selenium issues in the Delta. For example, high selenium concentrations were reported in white sturgeon (*Acipenser transmontanus*) tissues (Linares-Casenave et al. 2015) in the Bay and Delta. Laboratory studies showed kidney lesions, reduced growth, and deformities in Sacramento splittail (*Pogonichthys macrolepidotus*) that were fed a selenium-enriched diet (Deng et al. 2007). Populations of both species are exposed to high levels of selenium through their diet, notably from the overbite clam *Potamocorbula amurensis* (Feyrer et al. 2003; Stewart et al. 2013). Moreover, as part of the development of TMDL for the North Bay (Baginska 2015), extensive research has been conducted and revised criteria for the Bay were prepared, supported by an ecosystem-scale selenium model, a model of transport, fate, and uptake into the food web, and additional monitoring and review (Chen et al. 2012; Presser and Luoma 2013). Long-term trend monitoring by several agencies also continues (SFEI 2013; Stewart et al. 2013).

Monitoring programs for selenium have been conducted in San Francisco Bay for over 25 years by a variety of government agencies (e.g., USGS) and, more recently, as part of the Regional Monitoring Program for Water Quality in San Francisco Bay (Bay RMP; see

1 <http://www.sfei.org/rmp>). As part of the USGS monitoring program, selenium concentrations
2 have been examined in water, sediment, fish, bivalves, and bird eggs. In the mid-1990s
3 regulations reduced input of selenite and selenate forms of selenium from oil refineries in the
4 North Bay. A major effort associated with the San Joaquin-Grasslands Bypass Project
5 (<https://www.usbr.gov/mp/grassland/>) set targets for load reduction that the Central Valley
6 Regional Water Quality Control Board required. The approach used during this project has been
7 successful in that selenium loads from that region have been significantly reduced.

8
9 Tetra Tech, an environmental consulting firm, is examining historical selenium data in the Bay,
10 and some organizations are interested in proposing research projects to increase these efforts.

11
12 Since 2014, measurements of selenium in sturgeon muscle tissue have been made to determine
13 an appropriate TMDL for San Francisco Bay. More related to selenium in the Delta, some
14 monitoring has been done in rivers as they enter Suisun Bay. The Bay RMP is doing several
15 studies on tissues of white sturgeon, a species that moves from the Bay to the Delta. Selenium
16 concentrations in tissues are collected through “Sturgeon Derby” and muscle plug extractions in
17 Suisun Bay. A TMDL has been developed in the North Bay using concentrations in white
18 sturgeon as the indicator (Jay Davis, SFEI, pers. comm.). Research on the effects of selenium on
19 newly hatched larvae of sturgeon and their relationship to morphological deformities have
20 suggested that levels in some areas of the Delta approach those that have been shown to cause
21 deformities. The USGS conducts monitoring studies and research on *Potamocorbula* and
22 splittail in the North Bay and in the Delta. Findings suggest that selenium may be causing
23 developmental abnormalities in splittail. The Central Valley Regional Water Quality Control
24 Board has expressed interest in the selenium issue but selenium has not yet emerged as a top
25 priority for them. The Delta RMP is focused on several topics such as mercury, nutrients, and
26 pesticides, and although selenium may not be a high priority now, it is likely that more research
27 and monitoring will be needed in the future. The San Francisco Bay Regional Water Quality
28 Control Board has requested that the Bay RMP design a monitoring program to examine the
29 relationship between selenium and changes in hydrology. A goal of this monitoring would be to
30 determine whether there is a link between changes in selenium concentrations in North Bay
31 from water passing through the Delta. The Bay RMP does not extend to the Delta but considers
32 inputs from the Delta. The effect that the proposed California WaterFix project and other
33 upstream projects has on selenium dynamics is also of interest and related to Delta water
34 quality interests.

35
36 Although Johns et al. (2008) found no correlation between selenium and mercury
37 concentrations in the Delta, we are unaware of any research on whether the ameliorating
38 effect of selenium on mercury contamination have been examined in the Delta. However, these
39 interactions and the ameliorating effect of selenium on mercury contamination are of general
40 interest and are broadly studied in the wider research community (e.g., Yang et al. 2008;
41 Ralston and Raymond 2010).

42
43 Based on the interviews we conducted, we think that obtaining more information on direct
44 effects of selenium on fish would be a worthwhile effort. For example, developing an index of

selenium exposure from tissue is useful but selenium may have a greater effect on fish embryos and larvae. Selenium exposure in eggs may be an important topic for further research. Already, the concentration levels of selenium in sturgeon appear to be in a deleterious range. Many questions are not resolved and more monitoring of selenium and the need for testing of cause-effect relationships on biota in the Delta is needed in the Delta and San Francisco Bay, especially given the movement of fish across these connected habitats.

One scientist that we interviewed noted that selenium may be an increasing problem in the Delta. It is clearly a problem in the North Bay, which receives water from the Delta. Likewise, the Bay RMP indicates that selenium may become more of a problem in the future and more baseline information is needed (Tetra Tech 2017). As Fong et al. (2016) noted, a more precise understanding of the concentrations that elicit deleterious effects would be valuable information. This would be a worthwhile effort that would require additional research and the available monitoring data would be valuable in designing appropriate studies. There was only one specific comment that mentioned selenium in the questionnaire responses, which was, *“Potentially harmful chemicals are known to occur in the Delta, including selenium, but detection does not necessarily mean they are having an effect.”*

5. Chemicals of Emerging Concern

There is growing concern about whether ecosystem and human health can be protected from harm that might derive from new classes of chemicals being released into the environment. Chemicals such as PPCPs, newer industrial chemicals, and some current use pesticides, are often referred to as CECs. In some cases, CECs might be chemicals that have been in use for many years, but that are only being detected now because of improvements in analytical methods. Diamond et al. (2011) defined CECs as, *“chemicals that are known or suspected to be released to aquatic environments but are not commonly regulated or monitored, and whose potential risk to ecological health are relatively unknown.”* Generally, there are no standardized analytical methods or substantial toxicological data for CECs, which limits our ability to determine what risks, if any, are posed by their presence. Concerns about CECs in the Delta were nicely summed up by one respondent to our questionnaire, who said *“Chemicals of emerging concern will require increased vigilance and modifications of water quality monitoring and analysis programs.”*

Some studies have been done to determine the effects of CECs on aquatic organisms in the Delta (reviewed in Fong et al. 2016). Biological systems affected by PPCPs include immune function, osmoregulation, the nervous system, tissue structure, development, and behavior. While there is little evidence that single CECs are affecting organismal health at levels measured in the waters and sediments of the Delta, CECs are similar to pesticides in that they commonly occur as mixtures. For example, Biales et al. (2015) reported detections of up to 17 PPCPs in a single water sample taken from the Sacramento River in the spring of 2009. Moreover, while pesticides are generally applied in seasonal patterns, PPCPs have a more or less constant level of discharge, because they commonly derive from daily human activities.

1 Little is known about how mixtures of CECs, or CECs in combination with other Delta stressors,
2 might affect the ecosystem. The immediate challenge is to devise appropriate survey and
3 monitoring strategies that can help to determine the presence and potential risks that might be
4 posed by these substances. Towards that end, other systems have developed strategies,
5 including in Puget Sound (James et al. 2015), San Francisco Bay (Sutton and Sedlak 2015), and
6 Southern California (Mehinto 2017). The Southern California Coastal Water Research Project
7 proposes using cell-based assays to screen for chemicals having a common mode of action,
8 starting with chemicals that affect estrogen receptors (Mehinto 2017).

10 In May 2017, the Delta RMP helped convene a 2-day workshop about CEC issues in the Delta, to
11 learn about strategies developed in other systems, and to begin devising a CEC strategy for
12 California and the Delta. Key questions that were addressed during this workshop included: (1)
13 What types of studies are most critical for the Delta? and (2) Are there opportunities to partner
14 with other programs in California? This was a good initial step to take, but at the meeting it was
15 recognized that resources for the Delta RMP are constrained and are already inadequate to
16 meet the needs of the monitoring program they have recently started. In addition to the Delta
17 RMP, current efforts to monitor CECs include the USGS CEC monitoring of streams and the
18 SWRCB, which requires CEC monitoring of Recycled Waters. The Department of Toxic
19 Substances Control developed monitoring strategies for CECs in California aquatic ecosystems
20 with key prioritization principles based on potential exposure to chemicals and significant or
21 widespread adverse impacts to the environment.

23 As regional and state programs further evaluate the occurrence and impacts of CECs in the
24 environment, coordination between entities will be important. Examples of ways these
25 agencies can coordinate include the development of a consistent definition of CECs and use of
26 conceptual models to target appropriate media and determine a systematic prioritization
27 process to develop a target CEC list.

29 6. Algal Toxins

30 A prevalent concern of many of the questionnaire respondents was the presence of HABs/algal
31 toxins, especially those that transfer to the food web or otherwise influence ecosystem health.
32 Other comments on this topic included:

33 *“Additional monitoring and better availability of toxic algal bloom data would be helpful*
34 *- unclear at this time whether the recent programs will be sufficient to not only identify*
35 *locations of blooms but provide enough data to predict blooms in advance;”* and
36 *“CyanoHAB sources and environmental conditions leading to their blooms needs to be*
37 *researched.”*

38 Monitoring for both public health concerns as well as aquatic ecosystem health are also seen as
39 current shortcomings of responsible entities of the Delta. The most pervasive of these HABs for
40 the Delta are cyanobacteria (cyanoHABs), which include *Microcystis*, *Anabaena*, and
41 *Aphanizomenon*.

1 *Microcystis* was first reported in the Delta in 1999 (Lehman et al. 2005). This species produces
2 cyanotoxins (i.e., microcystins, lipopolysaccharides) that accumulate in the food web (Lehman
3 et al. 2010) and cause harm or death to wildlife, domesticated animals, and humans through
4 promotion of tumors and liver cancer (Zegura et al. 2003). *Microcystis* is the only consistently
5 occurring harmful algal species in the Delta. It has been shown to be deterred by temperatures
6 below 19°C and high turbidity (Lehman et al. 2013); therefore, this species is frequently
7 decimated by the onset of fall conditions in the Delta. However, as warm water temperatures
8 extend later in the season, this may extend the ability of *Microcystis* to remain actively growing
9 in the water column for longer periods of the year.

10
11 Current efforts addressing the threats of HABs in California waterways have been spearheaded
12 by the SWRCB's Surface Water Ambient Monitoring Program (SWAMP) and the CWQMC.
13 CWQMC's California Cyanobacteria and Harmful Algal Bloom (CCHAB) Network disseminates
14 timely information regarding HAB reported locations
15 (<http://www.mywaterquality.ca.gov/habs/>) and hosts a decision framework for managers and
16 the public to notify others about potential cyanoHAB concerns. The CCHAB Network advises the
17 public to be cautious when recreational exposure reaches 0.8 µg/L microcystin (CWQMC 2016).
18 Although this is stricter than the EPA drinking water health advisory of 1.6 µg/L microcystin (US
19 EPA 2017), Lehman et al. (2010) show accumulations of microcystin and liver lesions in Delta
20 sportfish where *Microcystis* were reported as comprising 100% of surface phytoplankton, and
21 dissolved microcystin concentrations (0.00005-0.01088 µg/L) were 73x lower than the above
22 trigger caution action levels. These findings support the continued need for further focused
23 studies to understand how cyanotoxins affect wildlife in the Delta and what these effects mean
24 for the overall ecosystem health.

25
26 The Southern California Coastal Water Research Project developed a white paper on
27 cyanoHABs (Berg and Sutula 2015), their relevance to Delta waterways, and determining gaps
28 of knowledge in understanding HABs. Two major recommendations from Berg and Sutula
29 (2015) are to develop and fund a 3- to 5-year monitoring and special study program to monitor
30 cyanoHABs in the Delta and to assess the toxicological risk of cyanotoxins to people and
31 wildlife. The monitoring program would develop an ecological model to better understand
32 drivers and controls on primary production and phytoplankton assemblage in the Delta. These
33 results will be useful in determining what triggers *Microcystis* bloom initiation and
34 development, and what determines the size of final bloom and thus the geographical extent of
35 concern after bloom die off.

36
37 Although HABs such as *Microcystis* have been found in the Delta on a consistent basis since
38 their initial detection in 1999, routine monitoring of at-risk locations for bloom development
39 during peak trigger conditions should be carried out more comprehensively. These programs
40 could be added to current long-term monitoring efforts as resources become available.
41 Anderson-Abbs et al. (2016) illustrate additional shortcomings, specifically that landscape risk
42 assessment is missing completely from current efforts, while other monitoring and forecasting
43 efforts such as waterbody monitoring and immediate or long-term bloom response are carried
44 out in various levels of comprehensiveness by responsible agencies. Given that the known

triggers of *Microcystis* blooms, which include warm, slow, and clear waters, are likely to become more prominent with climate change, it is important to address HAB formation and identify mitigation actions as a short-term management priority.

More structured and exhaustive monitoring for HABs and toxins should be carried out to more effectively forecast bloom inception and mitigate for occurrence. SWAMP is completing guidance documents for decision making regarding HAB development as well as undertaking development of a publically available database for timely dissemination of legacy and current data regarding blooms, including satellite imagery of any bloom events (Anderson-Abbs et al. 2016). SWAMP has set aside resources for completing guidance documents and standard operating procedures for response to and management of freshwater HAB development (Anderson-Abbs et al. 2016). However, the recommendations set forth cannot be fully implemented without additional resources. Continued support for landscape-scale risk assessment and endorsing crosstalk between monitoring groups is key to managing HABs as the Delta faces uncertain threats in a changing climate.

IV. Key Points from the Delta ISB Questionnaire

In this section, we highlight some of the key points identified by the questionnaire respondents. A more detailed presentation of the responses is provided in Appendix A, while the list of respondents is given in Appendix B. Key points are provided in bold type and supporting quotes were copied verbatim from the questionnaire responses. These points were selected to represent the diversity of perspectives expressed in the responses to the questionnaire and should not be considered as being endorsed by the Delta ISB.

Water quality is defined in a variety of ways depending on different stakeholder groups and agencies (e.g., for drinking water, agricultural use, and ecosystem health). Consequently, criteria and priorities regarding different water quality constituents vary, and become complex.

“We recognize that to understand water quality and ecological processes it is important to look at many constituents concurrently, including: DBPs, dissolved organic carbon (DOC), pH, total suspended sediment/turbidity, light penetration, and also biological components such as chlorophyll, blue-green algae and cyanotoxins, and phytoplankton taxonomy and size.”

“Let’s get serious about water quality. Up until this time only “one agency” has been really serious about Delta water quality for urban uses. The other members of the California Urban Water Agencies have been more interested in wet water and protecting their ability to export water, or are not invested in Delta water quality because they divert their water upstream of the Delta. Some, through CWF (California WaterFix), are hoping to also divest themselves from worrying about (protecting) Delta water quality by taking their water very close to the Sacramento inflow point to the Delta. Those that discharge wastewater or agricultural drainage into the Delta are also not interested in improving Delta water quality, which is why ACWA

(Association of California Water Agencies) seldom fully engages in protecting Delta water quality. Unless this is solved at a policy/political level, there will never be enough support on a financial, technical or legislative level regarding water quality in the Delta.”

Multiple stressors related to water quality affect the Delta ecosystem and these must be examined more closely.

“The effects of multiple compounds and the effects of these compounds combined with other abiotic stressors (e.g., increased temperature, increased salinity, reduced habitat range) needs more attention along with the sublethal effects that can lead to decreased abundance or genetic diversity.”

The interactions between contaminants and other stressors require more attention.

“More research is necessary to determine the impacts to individuals and population from the interaction of contaminants and other stressors (e.g., altered temperature, predation, and mixtures).”

“Pesticides, particularly additive and synergistic adverse effects of multiple pesticides and degradates; nutrients; and CECs, some of which may have additive and synergistic adverse effects with pesticides and pesticide degradates.”

“Mixed effects and interactions (e.g., temperature and contaminants, zooplankton feeding rates and contaminants).”

There is no comprehensive contaminants monitoring and assessment program looking at their relationship with ecological processes.

“What drivers and/or mechanisms influence the fate and transport of these constituents? What are the impacts to listed fish and their habitat? At what temporal and spatial scale should we measure these constituents to support fisheries and aquatic beneficial uses? How does land use change (habitat restoration) play a role in supporting the ecological function of the Delta? Can we restore the healthy function of the system by studying 'only' these constituents; does the information we collect fit within a broader framework? What are the hot spots and hot moments at which these constituents occur and can we use this information to drive management decisions?”

“IEP Directors need to recognize the importance of water quality in ecosystem studies and commit to including more water quality expertise and integration into their studies.”

“For the most part sufficient research has been conducted to show the importance of water quality impacts to the Delta ecosystem and organisms; however, there does not appear to be sufficient information for regulatory agencies to prioritize aquatic ecosystem health over anthropogenic interests. This may require numerical models to show that seemingly minor

1 sublethal and indirect impacts to individual organisms can result in major population declines.
2 Both numerical and conceptual models are needed to help understand how sources, pathways,
3 transport, mechanisms (e.g., biological, chemical, and physical), and other management actions
4 (e.g., land use and sediment management) affect water quality.”
5

6 “Nearly all of the parameters that are the focus of this review suffer from a lack of consistent
7 and adequate temporal and spatial coverage.”
8

9 **Pesticides and other chemicals at low levels are not being assessed adequately for sublethal**
10 **effects or additive effects in concert with other stressors.**
11

12 “What are the cumulative impacts of pesticide application to waterways with sensitive fish
13 species? What are the direct and indirect, acute and sublethal effects of pesticides to fish and
14 their aquatic habitat? What are the habitat effects of increased nutrient loading and algal toxins
15 in the Delta? What are the hot spots and hot moments of pesticide, nutrient and
16 methylmercury production in the Delta, and what are the key drivers? What modeling efforts
17 are needed to improve our understanding of nutrient transport in the Delta; can we develop a
18 nutrient modeling effort?”
19

20 “Toxicity testing, as well as other evaluations of xenobiotic impacts to aquatic life physiology,
21 behavior, etc. is not adequate to support timely management decisions.”
22

23 “Toxicity testing and the other biological tools available that assess the health of organisms or
24 biological effects of exposure are highly underused. Biological testing helps understand the
25 dynamic, combined effects of multiple compounds present at any given time. Chemical analysis
26 alone is often problematic because of unknown bioavailability, but toxicity testing innately
27 provides the answer to whether or not something is bioavailable.”
28

29 “We need to fully understand the sublethal effects (from whole organism to molecular level) of
30 contaminants and the interaction of chemicals + say a water quality stressor. What is that
31 interaction of say the fish is starving because of inadequate food quality and supply, so what
32 happens when they are exposed to a chemical stressor or immune disease? The system is a
33 series of low-level effects that cumulatively have an adverse effect. EPA had conducted an in-
34 situ study at Hood on Sacramento River (see Biales et al. 2015). We need to continue this type
35 of work.”
36

37 **CECs will require increased vigilance and modifications of the water quality monitoring and**
38 **analyses programs.**
39

40 “As scientific research identifies risk thresholds for particular CECs, it would be useful to
41 determine their occurrences and concentrations in Delta waterways. A selection process
42 selecting candidate chemicals for future monitoring studies in the Delta would benefit from
43 stakeholder input and a public review. Focus on ambient water quality first, then determine if
44 problems exist.”

1
2 **Although the Delta is one of the best studied estuarine systems in the world, research is**
3 **needed in several areas.**

4
5 **1. Contaminants:**

6
7 “What are the cumulative impacts of pesticide application to waterways with sensitive fish
8 species? What are the direct and indirect, acute and sublethal effects of pesticides to fish and
9 their aquatic habitat? What are the habitat effects of increased nutrient loading and algal toxins
10 in the Delta? What are the hot spots and hot moments of pesticide, nutrient and
11 methylmercury production in the Delta, and what are the key drivers? What modeling efforts
12 are needed to improve our understanding of nutrient transport in the Delta; can we develop a
13 nutrient modeling effort?”

14
15 “Overall, contaminant and toxicity monitoring in the Delta requires more consistency and
16 thoroughness, and the studies need to be developed so they reflect impacts to key estuarine
17 species.”

18
19 “More than just measurement of chemicals, effects on organisms past standard chronic and
20 acute testing should be done.”

21
22 “Some key parameters that require more monitoring include the fate, transport, and ecological
23 impact of sediment bound contaminants (e.g., pyrethroid pesticides and mercury), PPCPs, and
24 the long-term toxicological effects (cumulative) of altered water quality.”

25
26 “We need to examine potential water and sediment toxicity with a diverse suite of test
27 species.”

28
29 **2. Nutrients:**

30
31 “More research is necessary for nutrient (e.g., forms and ratios) impacts to the Delta
32 ecosystem. In addition, the exchange of nutrients and food sources between the upper estuary,
33 lower estuary, near shore, and floodplains is likely necessary to support species recovery.
34 Understanding how to maximize these exchanges of nutrients and primary and secondary
35 production in these zones is necessary to improve the Delta ecosystem health.”

36
37 **3. Need for research on nutrients and aquatic weeds:**

38
39 “We don't really know how nutrients affect aquatic weed growth or the food web.”

40
41 “You might have asked how water quality data could be integrated with biological data. For
42 example, data integration that will help understand the role of nutrients in the distribution and
43 growth of aquatic weeds and harmful algae.”

1 **4. Need for more high frequency (HF) data, especially at locations where flow is**
2 **measured:**

3
4 “Measurements need to be made at higher frequencies at more flow stations to get at
5 processes - a good long-term high frequency base monitoring network needs to be developed
6 that should cover the entire estuary. Water quality parameter additions should be considered
7 when new sensors become available - sensor technology is advancing rapidly. Of course, the
8 data then also needs to be analyzed! Shorter-term, smaller, but more spatially intense HF
9 monitoring networks should augment this base HF monitoring network to address specific
10 questions of management concern, e.g., about the effects of the upcoming Sac Regional WWTP
11 conversion or specific wetland restoration actions. Also, more attention needs to be paid.”

12
13 “Again, focusing on collection of in situ high-frequency data: before I would add parameters or
14 stations, I would think about redirecting the current efforts. Between DWR and USGS, we have
15 a good flow network, but we often do not collect water quality data at the same locations that
16 flow is measured, which hampers our ability to correctly interpret that data. It seems to me
17 that it would assist the monitoring that is done by collection of discrete samples would benefit
18 from sampling at the same locations we are collecting continuous data, but this is often not
19 done.”

20
21 ***There is a need for improved collaboration among agencies.***

22
23 “Agencies and programs tend to naturally be siloed. It takes time and effort to coordinate and
24 integrate. The way to counter this is to present cohesive strategies on answering priority
25 management questions in the Delta. This requires buy -in and agency or entity management
26 commitment to the process. This can be done by addressing and prioritizing regulatory
27 information needs, then grouping like purposes and missions. Work teams or study groups are
28 then formed based on the grouping. Within each work team individual program's mandates and
29 needs are discussed and recognized. Resulting study efforts are designed to meet as many of
30 intersecting information needs, recognizing that some may not be met by an integrated
31 monitoring or study effort and will need to exist outside the coordinated effort. There still
32 should be a data connection where information can flow. Work teams need to include the
33 appropriate multidisciplinary members- such a biologists, geologists, water quality experts and
34 data management resources.”

35
36 ***Better linkages are needed between water quality monitoring that is done for regulatory***
37 ***compliance, with that being done for special studies and in research programs.***

38
39 “Research priorities are determined by permits and environmental compliance.”

40
41 “Because water quality regulations and management are primarily under the purview of the
42 Water Boards, the Department often coordinates with Water Board staff to determine the kind
43 of information they need to develop water quality criteria to protect natural resources. Yes,

1 understanding and achieving the water quality conditions necessary to protect natural
2 resources is important.”

3
4 ***The CWQMC needs funding and additional staff to be more effective. Alternatively, there are***
5 ***other agencies that could coordinate monitoring programs.***

6
7 “The CWQMC needs to focus on what they want to do--right now they are being opportunistic,
8 which is good, but there needs to be a guiding strategy, and I think that is changing and a little
9 unclear right now (likely because of a lack of funding).”

10
11 These other agencies include: the “Delta RMP”; “IEP (Interagency Ecological Program) but they
12 need a better database system. They would need more contaminants experts, like aquatic
13 toxicologists in their team. They are more fish centric.”; “The San Francisco Estuary Institute
14 (SFEI) and its information management and accessibility services could be better utilized.”;
15 “Delta RMP & IEP. A more Delta-focused group that actually does include hands-on monitoring
16 might be better.”; “The Delta RMP provides the proper organizational structure to design,
17 review, and report on new water quality monitoring activities in the Delta.”

18
19 ***Data management needs to be improved.***

20
21 “We are not making good use of the data we do collect and a key uncertainty is “other people's
22 QA/QC--there is a lot of data out there, whether or not it’s useable is another question.”

23
24 “Creation of data management plans should become standard operating procedures (SOPs) for
25 all monitoring efforts to ensure that data and metadata are properly managed and stored for
26 future use and access.”

27 “Both the CWQMC and the IEP are potentially the best to coordinate data storage. The former
28 is underfunded and understaffed. Alternatively, an NGO (such as SFEI) could do this.”

29 “To share data means having a common way to link up the data geo-spatially. Therefore, first
30 order is a minimum geo reference standard and SOPs should need to be developed and
31 required for each record so data can be connected in the real world. Second, for years we have
32 debated whose database platform water quality data should be housed in. This has always met
33 both personal and agency philosophy challenges and resources issues. Third, existing systems
34 have vocabulary comparability problems for similar categories of data, for example chemical
35 name, or units of measure.”

36 “The CWQMC Portal for the Delta has made great strides in bringing data together, mostly
37 through the work of 34 North and the IEP to integrate data into scientific visualization products.
38 Technology advancements are allowing us to think differently. Open data platforms are the
39 new and most promising approach. It allows groups to keep their data systems, but place data
40 sets outside of firewalls for access by tools to integrate. Vocabulary challenges are being
41 tackled by software that can look for compatibility with similar names and connect the values.
42 Programs still need to have sustainable data systems that provide similar fields including the

1 above mentioned spatial reference data, and metadata as a way to evaluate the quality of the
2 data. Real time sensor data is on the rise and available publically, but data quality review of
3 these large datasets and metadata describing the quality is problematic.”

4 5 **Data Visualization**

6
7 “The improvement that I would like to see is in data visualization. I know that SFEI is making
8 progress on data visualization with their EnVis portal, and that Bay-Delta Live is working on
9 visualization tools as well. But both are still well short of what is possible using commercial
10 products designed for visualization of large and complex data.”

11
12 “I believe centralization of Delta data in a single data warehouse and linking that data to
13 powerful and flexible visualization tools would be a great investment, and speed our
14 understanding of Delta processes.”

15 16 **There are some positive comments related to existing data management efforts.**

17
18 “Many recent advances in data sharing and good models for data sharing e.g., Water Quality
19 Exchange jointly developed by USEPA and USGS under National Water Quality Monitoring
20 Council.”

21
22 “Data sharing is good and could be improved, but the CDEC (California Data Exchange Center)
23 program and portal does an outstanding job.”

24
25 “There has been substantial progress in agency recognition and commitment to data sharing.”

26
27 “There are some redundancies in water quality monitoring and programs but there are
28 advantages to having redundancy in the system.”

29 30 **Adaptive management is, in general, not a part of water quality programs. However, some** 31 **agencies/programs are using adaptive management and can provide models for integrating** 32 **adaptive management into water quality.**

33
34 “We do not currently use an adaptive management approach in collecting water quality data,
35 or to inform management decisions.”

36
37 “Adaptive management in collecting water quality data is not particularly relevant for our
38 agency. We monitor what is required by law (i.e., even though we haven't found certain
39 constituents, we must continue to monitor for them) and what is necessary to continue to
40 deliver high quality of water to our customers.”

41
42 “We use a simple adaptive management approach. Data is first collected at key locations for a
period of time, analyzed, and the program is then adjusted as needed to reflect the needs of
our Agency.”

1 “We use an adaptive management approach to actively conserve and protect ESA listed species
2 and their habitat to meet recovery goals and objectives. We accomplish these goals through
3 our coordination on regional monitoring efforts and engagement with various water quality
4 stakeholders (state, federal, local, etc.). Our data needs and monitoring efforts are tied directly
5 to the current and future threats to our species such as pesticides, heavy metals, sediment,
6 etc.”

7 “A good example of adaptive management is the State Water Boards, SPoT (Stream Pollution
8 Trends) program, contact Dr. Dawit Tadesse. This is a model that should be examined. They
9 have a technical scientific review panel and input from entities. It has goals, assessment
10 questions, very good analytical team and uses a diverse suite of test species to use to assess
11 attainment of the assessment questions. They have reduced pollutants such as the OCs, PAHs,
12 and at the same time looking forward to what pollutants needs to be included in next
13 monitoring cycle based on the panel inputs too. Additionally, they are coordinating with CDPR
14 to have better coordination on focused monitoring to evaluate the effectiveness of
15 management decisions, such as pesticide use restrictions.”

16 **Funding is necessary for improvements in water quality monitoring and analysis.**

17
18 “The Delta RMP is the umbrella program regularly monitoring contaminants in the Delta, yet
19 they are focused on pesticides (as is the Irrigated Lands Regulatory Program) with some
20 proposed future work on nutrients and mercury. They only monitor five peripheral sites coming
21 into the Delta monthly and this is not sufficient either spatially or temporally. This doesn't
22 provide enough information to perform mass balance, identify sources and sinks, or generate
23 trend data for quite some time.”

24
25 “Additionally, data management has been poor and inconsistent across the multi agencies of
26 IEP. DWR management commitment to applied database needs at IEP for water quality and
27 biological data has been under-resourced for years and based on (Microsoft) Access data
28 platforms. This needs to be better. USGS groups receiving any state or federal Delta money for
29 Delta or watershed work needs to be held to providing data into designated systems in a more
30 timely manner, not only their NWIS (National Water Information System) system.”

31
32 “Currently, the Monitoring Council and its work groups operate largely on voluntary
33 contributions of staff time and other resources. “

34
35 **There is a need to understand the effects of changing Delta conditions and intended**
36 **management actions on water quality, especially as it is clear that climate change and other**
37 **factors in the future will bring about numerous changes.**

38
39 “I think in addition to the general questions, you could have asked some questions specific to
40 some ongoing or intended management actions, e.g., WaterFix tunnels, specific habitat
41 restoration projects, the Sac Regional WWTP conversion, Yolo Bypass, etc. For example, will
42 these actions affect water quality in a part of/the whole Delta? Is the current water quality

1 monitoring network sufficient to monitor and assess changes in water quality in specific parts
2 and/or the whole Delta that may result from these actions? What monitoring and research is
3 needed to determine if changes in water quality are due to these specific actions or something
4 else?"

5
6 "Proposed changes in water conveyance and changes in hydrology related to climate change
7 are likely to affect water quality."

8
9 **It is not clear how water quality data are being used in management decisions, and whether**
10 **the data are sufficient to support management decisions and policies.**

11
12 There are "some questions specific to some ongoing or intended management actions, e.g.,
13 WaterFix tunnels, specific habitat restoration projects, the Sac Regional WWTP conversion, Yolo
14 Bypass, etc. For example, will these actions affect water quality in a part of/the whole Delta? Is
15 the current water quality monitoring network sufficient to monitor and assess changes in water
16 quality in specific parts and/or the whole Delta that may result from these actions? What
17 monitoring and research is needed to determine if changes in water quality are due to these
18 specific actions or something else?"

19 V. Concluding Thoughts

20 Many of the comments that we received in both the interviews and the questionnaire
21 responses were concerned with issues surrounding water quality monitoring. The Delta ISB is in
22 the initial stages of developing a review of the extensive monitoring enterprise that is being
23 done in the Delta. For this reason, we have not emphasized the topic of monitoring in this
24 review of water quality. However, this present review has clarified the need for the Delta ISB to
25 examine specific issues related to monitoring and water quality, and these topics will be
26 included in the monitoring enterprise review.

27
28 Based on this present review, we clearly see the need to document and evaluate the water
29 quality components that are being monitored, who is monitoring them, and the way and
30 reasons that these components are being monitored. The upcoming monitoring review will also
31 include information about how monitoring data are being stored, analyzed, synthesized,
32 communicated, and used for decision making. Moreover, we anticipate that the response of the
33 agencies to the information provided in this water quality review will enable the monitoring
34 enterprise review to better identify additional components that should be monitored and
35 efficiently used in decision-making. We also anticipate that the information provided in this
36 water quality review will enable the Delta ISB to identify appropriate focused research that
37 should be done in conjunction with monitoring to help address uncertainties in scientific
38 understanding of Delta water quality.

39
40 Water quality has many meanings, depending on management interests and a variety of other
41 factors ranging from societal values to economic considerations. The mandates and
42 perspectives of the managers and users of water quality information will also determine which

1 constituents may be of concern, whether their concern is for fisheries, drinking water,
2 agricultural water, or other purposes. Although this report has not dealt in detail with source
3 reduction, great advances have been made in this area in recent decades. However, this
4 attention clearly should continue as a key management priority in terms of both future
5 reductions in point and non-point source discharges.
6
7

DRAFT

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VI. Appendices

Appendix A: Perceptions About Water Quality in the Delta: Responses to the Delta ISB Questionnaire

Quantitative Evaluations and Comments

The Delta ISB developed and sent out a questionnaire about the current state of water quality analysis being conducted in the Delta. Twenty-three respondents filled out the questionnaire and several others were interviewed in person. Questions were scored numerically in terms of a series of choices from strongly disagree with the statement to strongly agree. Respondents were also asked to make narrative comments for each question if they wished. A graphical presentation of responses received and examples of representative supportive comments follow below. Because perceptions about water quality can influence actions, consideration of these comments is helpful in making this report complete and useful.

Perceptions of Water Quality in the Delta

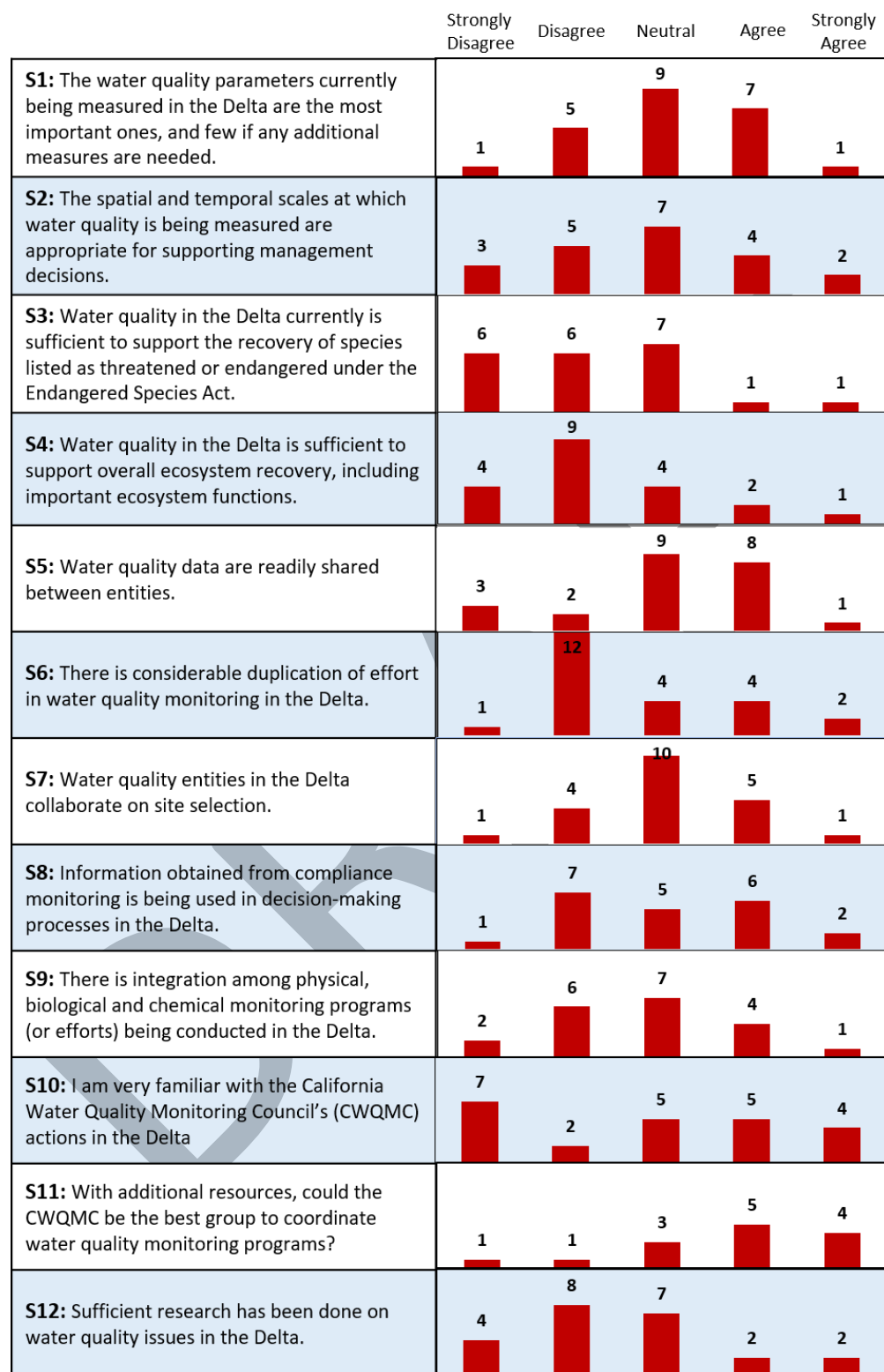


Figure 1. Summary of responses to the questionnaire that the Delta ISB distributed to assess perceptions about water quality across agencies and programs. As many as 23 responses were provided. The figure illustrates the diverse perspectives across the entities that are involved in water quality issues.

Question 1. The water quality parameters currently being measured in the Delta are the most important ones, and few if any additional measures are needed. The responses to this question produced a normal distribution with the range among five categories of strongly disagree to strongly agree being 4%, 22%, 39%, 30% and 4%, respectively.

This question produced many responses about the need for additional components to be examined:

- “Sucralose;”
- “The fate, transport, and ecological impact of sediment bound contaminants (e.g., pyrethroid pesticides and mercury), PPCPs, and the long-term toxicological effects (cumulative) of altered water quality;”
- “Toxicity testing, as well as, other evaluations of xenobiotic impacts to aquatic life physiology, behavior, etc.” are needed;
- pyrethroids : “Adverse impacts to aquatic life (e.g., LC50s, reduced fecundity) have been observed at pyrethroid concentrations 2-5 times lower than analytical methods can quantify;”
- “In situ ammonium and phosphate; strategically-placed continuous sensors that provide information about phytoplankton size and rudimentary taxonomic class” are needed; as are “multi-wavelength fluorescence sensors that permit tracking of wastewater. But, perhaps most importantly, sensors that can actually see the main HABs we have here;”
- “Aggregate sampling, or more important bioassay work at the boundary conditions and sources should be conducted;”
- “FDOM (Organic Carbon), Chlorophyll-a;”
- “methylmercury, pharmaceuticals, nutrients, algal toxins” should be measured at more sites;”
- “Metals, e.g., Cu, Ni, which are naturally occurring and have anthropogenic sources, not because of water quality concern but to help understand presence and sources of other pollutants of concern” should be examined;
- “*Hyalella* and *Chironimus* toxicity testing. CECs (pharmaceuticals and personal care products, flame retardants). Sub lethal fish effects” and analysis are needed.

Clearly, both the numerical responses and comments to this question indicate that there are different perceptions about whether current parameters being measured in the Delta are sufficient. Responses may reflect interests of either the agencies or the person responding to the questionnaire. However, several respondents mentioned a need for more mercury and pesticide testing.

Question 2. The spatial and temporal scales at which water quality is being measured are appropriate for supporting management decisions. Responses again indicated a normal distribution with the range among five categories of strongly disagree to strongly agree being 14%, 24%, 33%, 19%, and 10%, respectively. Specific responses included:

- “For salinity and flow, measurements are adequate which are in the permits. For toxicity and sub lethal effects there is inadequate spatial and temporal measurements. Discrete grab samples do not adequately capture the heterogeneity of the system;”
- “Pesticides (e.g., pyrethroids) should be measured at higher temporal resolution; nutrients fate and transport (nitrates and ammonia) and methylmercury production should be measured at higher spatial and temporal scales to identify when and where hot spots and hot moments occur, as well as what the drivers that influence the pools and fluxes of these constituents in the Delta;”
- “We need to test key indicator sites with a much higher frequency. We need to understand the tributaries which are the inputs to the Delta.....We should conduct more frequent sampling here to ascertain the major inputs to the system;”
- “Nearly all of the parameters that are the focus of this review suffer from a lack of consistent and adequate temporal and spatial coverage;”
- “Depending on what you want to do and what your goal is--modeling requires more. I don't think we are in a situation where any parameter is measured too much (at this point);”
- “We have insufficient nutrients and CECs data. We probably can cut back on mercury and methylmercury monitoring given our understanding of their presence, sources, and management actions;”
- “Measurements need to be made at higher frequencies at more flow stations to get at processes - a good long-term high frequency base monitoring network needs to be developed that should cover the entire estuary;”
- “Focusing on collection of in situ high-frequency data; before adding parameters or stations, I would think about redirecting the current efforts;”
- “We also have yet to make an effort to harmonize instrument calibration and data collection between the agencies that collect continuous water quality information in the Delta;”
- “Ammonium, phosphate and additional phytoplankton parameters were measurements that would help us better manage the system, but they should be deployed strategically. They will help us assess in real time the effects of management decisions on aquatic food webs;”
- “Additional frequency for SWAMP's SPoT monitoring would be beneficial. Their current monitoring frequency was deemed adequate for a relatively stable system, but the Delta is very dynamic;”
- “Spatial and temporal sampling methodology needs to take into account the hydrodynamics of the system.”

Question 3. Water quality in the Delta currently is sufficient to support the recovery of species listed as threatened or endangered under the Endangered Species Act. Responses were skewed in the direction of strongly disagree with the five categories from strongly disagree to strongly agree being 29%, 29%, 33%, 5%, and 5%, respectively. Many of the comments on this question refer back to the answers given above for Question 2. Specific responses included:

- “2 areas that need exploring-->timing of first flush (and what's in it and what the effects are) as it lines up with migration, and spraying for aquatic veg and the effects of the spraying;”
- “There are currently only about 10 water quality objectives or criteria for pesticides in the Central Valley, while over 1000 pesticide active ingredients are used in California... Herbicides likely reduce primary productivity in the Delta;”
- “USGS pesticide monitoring of the Sacramento and San Joaquin river inputs in the Delta showed that all samples contained mixtures of 3 to 14 pesticides. Pesticides reduce the benefit of the already limited aquatic life habitat in the Delta. Most of the Delta and tributaries are currently 303(d) listed for unknown toxicity, pesticides, and metals;”
- “Dissolved oxygen objectives (6 mg/L) in the Stockton DWSC were developed to be barely adequate to allow salmonid passage during fall-run adult migration;”
- “The POD has occurred concurrently with reduced phytoplankton and zooplankton abundance, which make up the food web. The cause of the decline of these lower trophic levels is unknown; however, some of the hypothesized causes include invasive clams, ammonia discharges from Sacramento Regional San or adjustments to nutrient ratios, and pesticide discharges. Monitoring will be necessary to partition the possible impacts of these and other factors to food web and fish declines;”
- “Until about a decade ago, fish were thought to be insensitive to mercury toxicity; however, research has found that they are as sensitive, if not more sensitive as humans;”
- “The impacts of current pesticides used primary in agricultural landscapes; pollutants in urban stormwater runoff; production of methylmercury as a result of land use disturbance, and pharmaceuticals are aspects that of water quality hindering recovery;”
- “Nutrients are probably the biggest water quality issue for endangered species recovery. Pesticides probably have more localized impacts but cumulatively may be important;”
- “Sublethal effects (i.e., endocrine disruption) of pharmaceuticals and contaminants of emerging concern should be evaluated more;”
- “We know that sometimes, in some places, water in the Delta is toxic to test organisms which means it's likely one factor that's hindering recovery. What continues to be unclear because of insufficient monitoring is how widespread and severe (by itself, and relative to other stressors) this problem really is and how it affects the habitats favored by endangered species. We also don't always know what caused the observed toxicity;”
- “It is my understanding that folks currently believe species declines in the Bay Delta are related to disruption in food webs consequent to a change in phytoplankton community composition. If we seek to restore these food webs, we need better information about them then can be obtained in weekly or monthly grab sampling programs;”
- “Whether contaminants helped shift the ecosystem to favor invasive weeds is yet unknown, but it seems clear that these weeds have increased clarity, reduced DO and flow, and provided cover for predators; all hindering the recovery of these fish;”
- “Pesticides and CECs having sub lethal or food web effects. Low DO in back sloughs. Also physical habitat and temperature are hurting resiliency;”

- “Continued support of the clear water lake concept to maintain low salinity at the pumps has created an altered ecosystem that eliminates natural tidal flux. The loss of seasonal flooding of wetlands and subsequent drainage has created greater water clarity and loss of transported organic matter and food chain organisms.”

Question 4. Water quality in the Delta is sufficient to support overall ecosystem recovery, including important ecosystem functions.

Responses were somewhat skewed in the direction of strongly disagree in five categories from strongly disagree to strongly agree, with responses being 20%, 45%, 20%, 10%, and 5%, respectively.

Several of the responses referred back answers given to previous questions. Additional comments included:

- “Continued support of the clear water lake concept to maintain low salinity at the pumps has created an altered ecosystem that eliminates natural tidal flux. The loss of seasonal flooding of wetlands and subsequent drainage has created greater water clarity and loss of transported organic matter and food chain organisms. The lower estuary looks like a freshwater lake, not a tidal marsh;”
- “Ecological function in the Delta is altered by dramatic changes in land use, such as increased pesticide application and nutrient inputs to salmonid-bearing streams, that far exceed the rate of store or the ability of the Delta to 'process' these constituents. Some of the underlying aspects/mechanisms (hydrology, habitat, climate change) that drive these ecological processes are poorly understood. How do these drivers affect listed species and what are the effects at various level (sublethal); and spatial and temporal scales;”
- “Endangered species depend on a functioning ecosystem/ecosystem functions that support the reproduction, growth, and survival...;”
- “The Delta's water quality is not sufficient to support overall ecosystem recovery;”
- “There is reduced abundance of key species: some due to food web effects and some to direct effects of contaminants (e.g., straying, inhibiting olfactory queues for ripe females and predators, reduced fecundity). The energetic cost of coping with contaminants can decrease food intake and this is particularly concerning for species already known to be starving;”
- “The effects of multiple compounds and the effects of these compounds combined with other abiotic stressors (e.g., increased temperature, increased salinity, reduced habitat range) needs more attention along with the sublethal effects that can lead to decreased abundance or genetic diversity.”

Several respondents indicated that high nutrient loads, eutrophication, methylmercury, pesticides, and CECs are very important in preventing recovery.

Question 5. Water quality data are readily shared between entities. Responses were skewed in the direction of strongly agree in the five categories of strongly disagree to strongly agree,

1 with the range being 13%, 9%, 39%, 35%, and 4%, respectively. Several comments were
2 provided in the responses:

- 3 • “To share data means having a common way to link up the data geo- spatially.
4 Therefore, first order is a minimum geo reference standard and SOPs should need to be
5 developed and required for each record so data can be connected in the real world.
6 Second, for years we have debated whose database platform water quality data should
7 be housed in. This has always met both personal and agency philosophy challenges and
8 resources issues. Third, existing systems have vocabulary comparability problems for
9 similar categories of data for example chemical name, or units of measure. The CWQMC
10 for the Delta has made great strides in bringing data together, mostly through the work
11 of 34 North and the IEP to integrate data into scientific visualization products.
12 Technology advancements are allowing us to think differently. Open data platforms is
13 the new and most promising approach. It allows groups to keep their data systems, but
14 place data sets outside of firewalls for access by tools to integrate. Vocabulary
15 challenges are being tackled by software that can look for compatibility with similar
16 names and connect the values. Programs still need to have sustainable data systems
17 that provide similar fields including the above mentioned spatial reference data, and
18 metadata as a way to evaluate the quality of the data. Real time sensor data is on the
19 rise and available publically, but data quality review of these large data sets and
20 metadata describing the quality is problematic;”
- 21 • “Need a central repository that is more regularly updated. MWQI is good but QA/QC
22 slows time for data to be posted. CDEC is real time but a big problem is that data gaps
23 (due to problems with the radio telemetry) or “typos” are not subsequently added or
24 correctly;”
- 25 • “Data is not shared or easily available by (i) the Universities and (ii) local agencies. This is
26 often a result of no readily available public platform to submit/upload this data to;”
- 27 • “Sharing is increasing, particularly between Bay and Delta monitoring efforts for
28 nutrients, but improvements needed to support nutrient water quality modeling. We
29 could improve sharing of Bay CECs monitoring with the Delta;”
- 30 • “The improvement that I would like to see is in data visualization;”
- 31 • “Generally, groups seem to have less politically-induced inhibition when it comes to
32 sharing water quality data than biological survey data, but how that data is shared
33 needs facilitation.”

34
35 **Question 6. There is considerable duplication of effort in water quality monitoring in the**
36 **Delta.** Responses were skewed in the direction of strongly disagree in five categories of strongly
37 disagree to strongly agree with the range being 4%, 52%, 17%, 17%, and 9%, respectively.
38 Strong opinions were expressed in the comments received:

- 39 • “This is a reoccurring fallacy I have heard about all monitoring programs across the
40 state. The point is each entity develops Data Quality Objectives based on mandates and
41 management questions, and these determine frequency, location, data quality, and
42 parameters. Rarely do these match someone else's needs. Some of the categories

1 include research, compliance, and ambient for trends, with each one requiring different
2 species;”

- 3 • “There is redundancy throughout the Delta for some water quality constituents by
4 different State & federal agencies;”
- 5 • “There is some duplication, but I actually find some (but not too much) redundancy to
6 be a good thing. I think a bigger problem is inefficient coordination of field runs to
7 service moored stations;”
- 8 • “There is so little contaminant monitoring, I no longer see the duplication there once
9 was.”

10
11 **Question 7. Water quality entities in the Delta collaborate on site selection.** Responses fell
12 into a normal distribution in a range of strongly disagree in five categories of strongly disagree
13 to strongly agree being 5%, 19%, 48%, 24%, and 5%, respectively. No additional comments
14 were received for this question.

15
16 **Question 8. Information obtained from compliance monitoring is being used in decision-**
17 **making processes in the Delta.** Responses were skewed in both the direction of strongly
18 disagree and strongly agree in five categories of strongly disagree to strongly agree being 5%,
19 33%, 24%, 29%, and 10%, respectively. However, no additional comments were added in
20 response to this question.

21
22 **Question 9. There is integration among physical, biological and chemical monitoring programs**
23 **(or efforts) being conducted in the Delta.** Responses were slightly skewed to disagree with this
24 statement with a range in five categories from strongly disagree to strongly agree being 10%,
25 30%, 35%, 20% and 5%, respectively. Several comments were received:

- 26 • “Top down management direction” is needed;
- 27 • “Agencies and programs tend to naturally be siloed. It takes time and effort to
28 coordinate and integrate. The way to counter this is to present cohesive strategies on
29 answering priority management questions in the Delta. This requires buy-in and agency
30 or entity management commitment to the process. This can be done by addressing and
31 prioritizing regulatory information needs, then grouping like purposes and missions.
32 Work teams or study groups are then formed based on the grouping. Within each work
33 team individual program's mandates and needs are discussed and recognized. Resulting
34 study efforts are designed to meet as many of intersecting information needs,
35 recognizing that some may not be met by an integrated monitoring or study effort and
36 will need to exist outside the coordinated effort. There still should be a data connection
37 where information can flow. Work teams need to include the appropriate
38 multidisciplinary members- such a biologists, geologists, water quality experts and data
39 management resources;”
- 40 • There is a need for “(1) Continued support of cross-discipline workshops like the Bay-
41 Delta Conference, (2) a public data repository for local agencies or universities to submit
42 data, and (3) development and support of a easy to use searchable water quality
43 platform that links to the share repository and various State/Federal databases;”

- There is a “Need to have good discussions and recommendations about 1) timing of samples evaluated (coverage over a range of seasons) to capture the breadth of potential chemicals, 2) location of the samples in relationship to the discharge from point sources and the runoff from agriculture, and 3) sample type to be more representative in relation to the frequency of the parameter” under investigation;
- “Integration might be improved by having a third party evaluate the monitoring programs, make recommendations for better integration, and facilitating discussions among monitoring entities;”
- “In some cases, the integration is great. In other cases, I read papers on water quality that lack recognition of the physical processes and misinterpret the data because transport and mixing are neglected.”

Question 10. I am very familiar with the CWQMC actions in the Delta. Responses were somewhat evenly distributed over the range of the five categories from strongly disagree to strongly agree being 30%, 9%, 23%, 22% and 17%, respectively. No additional comments were received for this question.

Question 11. With additional resources, could the CWQMC be the best group to coordinate water quality monitoring programs? If not, what is needed to make them even more effective? If the CWQMC is not the best group to coordinate water quality monitoring programs, is there an entity that could better perform this function?

Responses were skewed in the direction of strongly disagree in the range of five categories from strongly disagree to strongly agree being 20%, 45%, 20%, 10%, and 5%, respectively. The many comments received reflect the diversity of opinions on this issue:

- “Currently the CWQMC only has 1.3 staff to work towards achieving the goal of improved coordination of monitoring efforts. Additional resources (staff and funding) would most certainly help to improve the CWQMC 's ability to work towards this goal;”
- “Dedicated funding is needed to allow each relevant agency to participate in the CWQMC's work group efforts and resources to enhance data management, documentation, and sharing between agencies. The CWQMC would be more effective if its membership were to be expanded to include additional governmental organizations that serve key roles in water quality and ecosystem health monitoring, assessment, and reporting;”
- “A Google search barely finds anything on the CWQMC. Clearly, there is much work to be done if this is to be a public WQ portal for the Delta;”
- “The CWQMC is a great platform for allowing multiple entities to address statewide issues, such as data quality, data sharing, and emerging problems such as CyanoHABS. The portal approach for the Delta is a good platform for access and visualization. I believe IEP is the best entity but water quality issues in the ecosystem are underrepresented in the IEP study design, which is decided largely by fisheries and food chain biologists. Additionally, the Water Board water rights Division scientific participation technically needs to be stronger, since flow and salinity are often brought up in the hearings, versus other potential water quality issues;”

- “Yes, if they would add links to DWR water quality and other agency's web sites;”
- “The CWQMC has a much broader scope than just the Delta and doesn't do any hands-on monitoring itself. A more Delta-focused group that actually does include hands-on monitoring might be better, e.g., the evolving Delta RMP or the long-established IEP. Also, water quality monitoring should be closely coordinated and integrated with all other monitoring in the Delta; I don't think the CWQMC is in the best position to do this, the IEP is probably a better group for this. I think the CWQMC may have the biggest impact by bringing together and making all monitoring data available and visualizing and interpreting it in a publicly accessible way, and putting it in a statewide context. Another important role might be to guide and advise on water quality monitoring in the Delta;”
- “One of the CWQMC goals is to improve coordination of monitoring programs in the Delta and statewide. There are few (if any) organizations whose main purpose is to try and improve coordination of monitoring efforts (and access to data);”
- “Currently, the CWQMC and its work groups operate largely on voluntary contributions of staff time and other resources. Even with this obstacle, the CWQMC and its work groups have made tremendous progress toward standardizing methods and bringing data and information together from multiple agency programs.”

Question 12. Sufficient research has been done on water quality issues in the Delta.

Responses were skewed in the direction of strongly disagree in five categories of strongly disagree to strongly agree being 17%, 34%, 30%, 9% and 9%, respectively. Comments received include:

- “For the most part sufficient research has been conducted to show the importance of water quality impacts to the Delta ecosystem and organisms; however, there does not appear to be sufficient information for regulatory agencies to prioritize aquatic ecosystem health over anthropogenic interests. This may require numerical models to show that seemingly minor sublethal and indirect impacts to individual organisms can result in major population declines. Both numerical and conceptual models needed to help understand how sources, pathways, transport, mechanisms (e.g., biological, chemical, and physical), and other management actions (e.g., land use and sediment management) affect water quality;”
- However, “More research is necessary for nutrient (e.g., forms and ratios) impacts to the Delta ecosystem. In addition, the exchange of nutrients and food sources between the upper estuary, lower estuary, near shore, and floodplains is likely necessary to support species recovery;”
- “More research is necessary to understand the role of reduced turbidity (or increased water clarity) on Delta species declines; whether it has been caused by reduce sediment inputs, reduced phytoplankton growth, increased submerged aquatic species, increased residence time (sedimentation), etc.; and, whether it can and needs to be mitigated;”
- “More research is necessary to determine the impacts to individuals and population from the interaction of contaminants and other stressors (e.g., altered temperature, predation, and mixtures);”

- “Sublethal effects, additive effects of contaminants in the Delta. In vivo exposure studies at boundary conditions. Lab studies of threshold effects of related contaminants. Gene expression and behavioral effects. CEC monitoring. Determining relative sources of contributions of pesticides (Ag islands versus upstream watershed loading)” are topics needing additional examination;
- “Understanding the fate and transport of Emerging Contaminants (i.e., hormones, medicines), Pyrethroids, and other constituents from urban storm water runoff into the Delta;”
- “There is much to learn about the impacts of pesticides, nutrients, algal toxins, and methylmercury in the Delta. Questions to consider include: What drivers and/or mechanisms influence the fate and transport of these constituents? What are the impacts to listed fish and their habitat? At what temporal and spatial scale should we measure these constituents to support fisheries and aquatic beneficial uses? How does land use change (habitat restoration) play a role in supporting the ecological function of the Delta? Can we restore the healthy function of the system by studying 'only' these constituents; do the information we collect fit within a broader framework? What are the hot spots and hot moments at which these constituents occur and can we use this information to drive management decisions?;”
- There is a need to better understand “Phytoplankton community structure, size and productivity; beneficial phytoplankton bloom inception, propagation and transport; harmful phytoplankton bloom inception, propagation and transport; nutrient forms, sources and sinks; wetland nutrient utilization as well as phytoplankton and dissolved organic carbon evolution; non-phytoplankton sources of energy available to Delta food webs; wastewater effects; nutrient uptake and transformation rates in both pelagic and benthic environments; nutrient and constituent exchange that occurs when water is circulated through Delta peat islands; mixed effects and interactions (e.g., temperature and contaminants, zooplankton feeding rates and contaminants);”
- “Additional research regarding the ecological effects of contaminants and nutrients is possibly needed. The need for additional sediments in the Delta is a topic that needs more research - especially the composition and size of sediments needed for aquatic organisms. Suspended sediments versus bed sediments.”

Appendix B: Respondents to the Delta ISB Questionnaire About Water Quality in the Delta

Respondent entities¹ (in alphabetical order):

California Department of Fish and Wildlife, Water Branch
California Department of Water Resources
California Department of Water Resources, Municipal Water Quality Program Branch
California Parks and Recreation, Division of Boating & Waterways
California Water Quality Monitoring Council
California Water Quality Monitoring Council
Contra Costa Water District
Delta Science Program
Irrigated Lands Program, Central Valley Water Board
NOAA Fisheries
Sacramento-San Joaquin Delta Conservancy
San Francisco Bay Regional Water Quality Control Board
Solano County Water Agency
State and Federal Contractors Water Agency
State Water Resources Control Board, Division of Drinking Water
State Water Resources Control Board, Office of Information management and Analysis
State Water Resources Control Board, Pesticide Permitting Program
US Environmental Protection Agency, Region 9
US Geological Survey
US Geological Survey, California Water Science Center

Plus two individuals reporting for themselves and an anonymous respondent.

¹ Respondents were not asked to represent the views of their respective entity.

Appendix C. Individuals from entities that we spoke with during this review (in alphabetical order). In some cases, we spoke with different individuals than those who responded to the questionnaire.

California State Water Resources Control Board
Central Valley Regional Water Quality Control Board
California Water Quality Monitoring Council
Delta POD – Contaminants Work Team
Delta Nutrients Forms and Ratios Public Workshop
Delta Regional Monitoring Program
Delta Science Program
Department of Water Resources
Sacramento Regional County Sanitation District
State and Federal Contractors Water Agency
UC Berkeley
UC Davis
US Environmental Protection Agency
US Geological Survey